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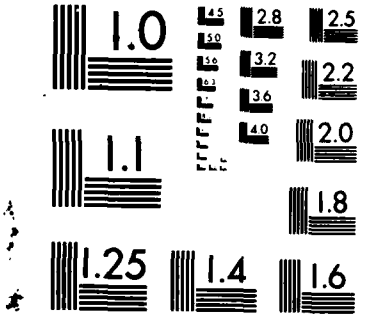

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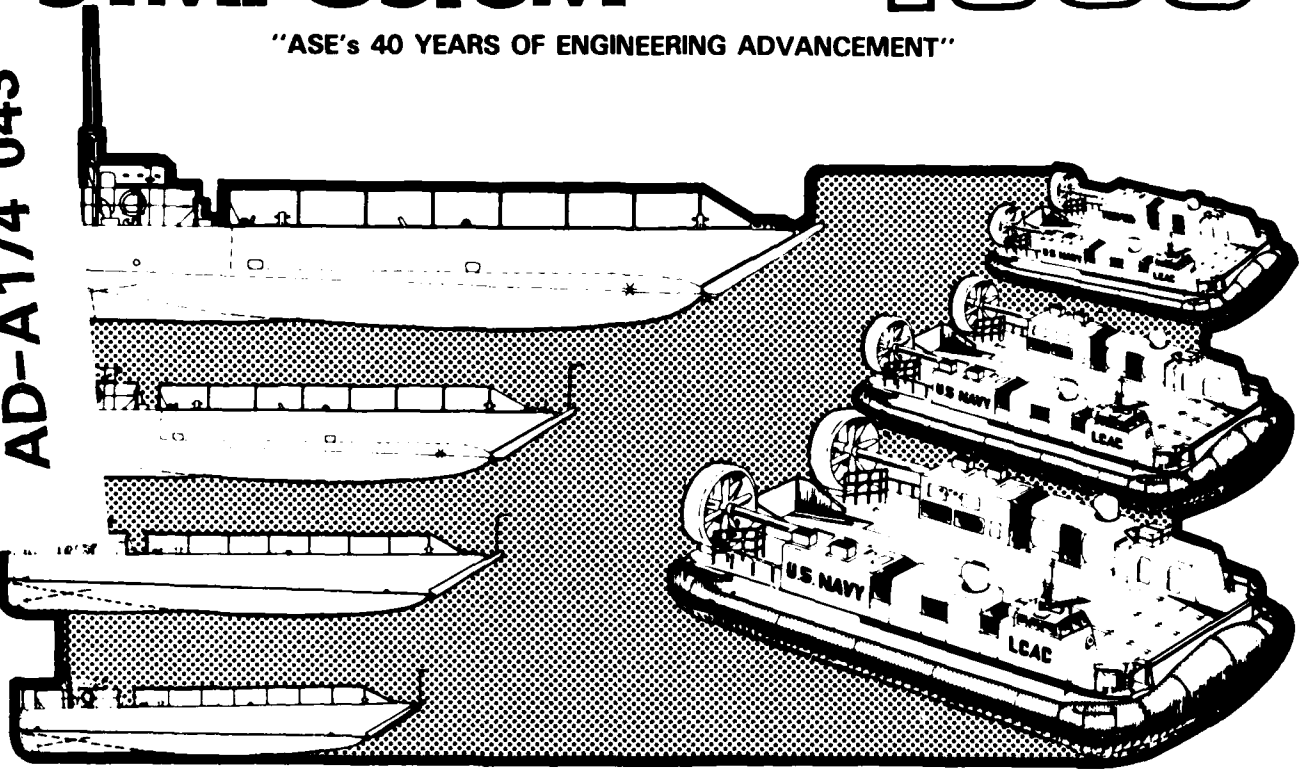

HUMAN ENGINEERING RESEARCH

by: F. Oberman

ASSOCIATION OF SCIENTISTS AND ENGINEERS OF THE NAVAL SEA SYSTEMS COMMAND • DEPARTMENT OF THE NAVY • WASHINGTON, D.C. 20362

HUMAN ENGINEERING RESEARCH

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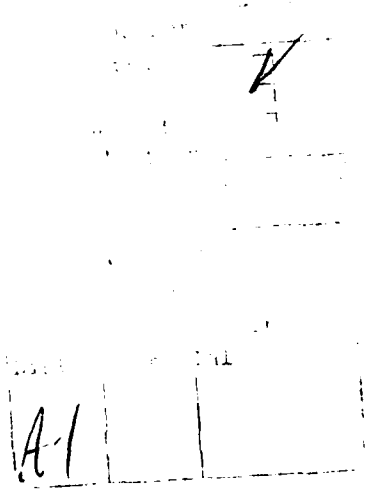
Abstract

Human engineering research in the Ship Design and Engineering Directorate of the Naval Sea Systems Command is primarily concerned with solving operational problems with man-machine interfaces in the fleet. Research interests therefore range from complex control/display issues and high technology effects to biodynamic, biomechanical, anthropometric, and environmental considerations.

Above all, human engineering research and development emphasizes using fleet feedback information and lessons learned reports to ascertain real problems, prioritize problems in terms of magnitude and importance of effects, and suggest/direct research oriented to design solutions. Proposed research recently advocated includes work on women onboard ships, lighting, alarms, protective ensembles, as well as investigation of a total research approach, from problem identification to improved ship design.

Table of Contents



1) Background

As a result of the Naval Research Advisory Committee (NRAC) report on Man-Machine technology in the Navy, (1980) (reference 1), and a GAO report on the need to expand the application of human factors in the military, (1981) (reference 2), the need for a human factors functional responsibility was reestablished in the Naval Sea Systems Command (NAVSEA). In 1983 NAVSEA formally established a human factors organization (SEA 55W5), and in the following year a human engineering Branch was created as SEA 55W54 (reference 3). In 1985 a NAVSEA human factors instruction was published (reference 4) which defined organizational responsibilities for human factors in NAVSEA.

SEA 55W5 is responsible for total ship human factors in NAVSEA. This organization is composed of four branches: Manning; Habitability; Supportability; and Human Engineering. The human engineering function in SEA 55W54 has grown from a one-person operation in 1983 to the current staffing level of five permanent staff members supported by engineers-in-training (EITs) and student trainees (CO-OPS).

2) Research Requirements

The emphasis to date in SEA 55W54 has been on applying available human engineering technology to ship and ship system design and construction. However, SEA 55W54 has recently initiated human engineering research and development (R&D) efforts specifically for HM&E systems. Human engineering R&D for combat systems is the responsibility of SEA 06. The interest in R&D in SEA 55W5 stems from the realization that serious personnel problems exist in the fleet today, for which research is urgently needed to develop and implement practical, effective, timely and economical solutions.

Five general types of R&D problems of interest to SEA 55W5 are those related to: personnel availability, personnel capability, personnel performance, personnel life support and safety, and system costs as a function of personnel factors. Personnel availability and personnel capability are primarily concerned with manning and training, respectively. The last three types of personnel problems: performance, safety and cost, are concerns for human engineering and are discussed in this paper.

Personnel performance problems include situations where qualified personnel do not perform to required standards. These problems are manifested in high error rates, excessive time to respond or to perform duties, or the simple inability to successfully perform assigned activities. Personnel performance problems can be caused by :

- personnel factors
- operational factors
- training factors
- procedural factors
- design factors

Personnel factors include inattention, oversight, misjudgment, inadequate reaction to stress, forgetting, fatigue, disorientation, distraction, reduced motivation, confusion, and inappropriate expectancy. Operational factors include: time constraints, inherent task difficulty, interfering activities, poor communications, and excessive workloads. Training factors include failure to train, failure to provide effective training, failure to provide retraining to refresh perishable skills, excessive training pipelines, and failure to keep training content current with changing system structure and function. Procedural factors include erroneous instructions and directives, incomplete or inconsistent operational sequences, and confusing directives. Design factors can be the most important influence on personnel performance problems. These factors include conditions where the design of the interface between the person and other system components (hardware, software, information, and environments) does not take into account the limitations of the human operator or maintainer. These human-machine interface design problems include such design inadequacies as: ineffective control and display location, arrangement, identification and operation; inadequate display format and readability; information overloads; unavailability of required information in a usable format; equipment design features which ignore such personnel characteristics as reach capability, body size, strength limits, sensory abilities, effects of clothing

conditions, and effects of environmental stressors. It is to the solution of performance problems resulting from such design deficiencies that the human engineering effort is usually addressed.

Personnel safety and life support problems include excessive accident rates and lost time and reduced personnel availability due to accidents. Safety problems, as performance problems, result from a variety of causes, but once again, the primary contributor is inadequate design.

Problems with system costs which are a function of personnel factors include the fact that personnel costs represent the major element of system life cycle cost. Total system operational and support costs can be dramatically reduced through attention to the optimal integration of personnel into systems and the effective utilization of personnel and automation. Excessive system costs also result from the personnel problems listed above. The GAO, in its 1981 report to Congress on the state of human factors in the military, noted that over half of the failures of military systems are the direct result of human errors. The Naval Safety Center established human error as the cause for 69% of the major accidents reported in carrier aircraft launch and recovery systems in the year 1984. Such accidents resulted in a loss of $85 million. It is obvious that, just as inattention to personnel requirements in the design and development of systems results in increased system cost, the application of human engineering in the design of systems will have a cost reduction/cost avoidance effect on the system through elimination/reduction of design-induced human error.

3) Categories of Naval Research

The major categories of Navy R&D are: basic research (6.1); exploratory development (6.2); advanced development (6.3); and engineering development (6.4). Basic research efforts include scientific study and experimentation directed toward increasing knowledge and understanding in those fields of the physical, engineering, environmental, biological-medical, and behavioral-social sciences related to long-term national security needs. It provides a portion of the base for subsequent exploratory and advanced developments in defense-related technologies and of new or improved military functional capabilities in areas such as communications, detection, tracking, surveillance, propulsion, mobility, guidance and control, navigation, energy conservation, materials and structures, and personnel support.

Exploratory development includes efforts directed toward the solution of specific military problems, short of major development projects. These include studies, investigations and minor development efforts pointed toward specific military problem areas with a view toward developing and evaluating the feasibility and practicality of proposed solutions and determining their parameters.

Advanced development includes all projects that have moved into the development of hardware for experimental or operational test. It is characterized by line item projects, and by the design of items directed to hardware for testing purposes as opposed to items designed and engineered for eventual Service use.

Engineering development includes those development programs being engineered for Service use but which have not been approved for procurement or operation.

4) Research in SEA 55W54

At present, 6.1 research is the responsibility of the Office of Naval Research. The Office of Naval Technology (ONT) controlled 6.2 human engineering research program is now block funded to the Naval Laboratories specifically, in the case of ship system human engineering, to the Naval Personnel Research and Development Center, San Diego. SEA 55W5 maintains awareness of and provides consultation to the 6.2 human engineering program, but is presently not involved in the direct management or conduct of the program.

The 6.3 human engineering for ships program is sponsored by OP-01B7G. SEA 55W5 has maintained contact with OPNAV concerning both generic and specific ship applications. Generic problem descriptions and need justifications (PD&NJs) were initially prepared for POM 87 and more extensively for POM 88, the details of which will be discussed later in this paper. In addition, the NAVSEA Human Engineering Branch is pursuing two courses of action for obtaining research funding for problem solutions on an advanced frigate design program; the particular

concern being allocating functions between man and machine and optimizing human engineering considerations to reduce manning and personnel skill levels and to improve system performance.

5) Generic 55W5 6.3 Human Engineering Program

In the 6.3 OPNAV human engineering program the System Commands act as requirements managers and evaluate Technical Development Options (TDOs) prepared by the naval laboratories in response to SYSCOM generated PD&NJs. When the laboratories do not prepare a TDO for a PN&NJ, then the NAVSEA human engineering element, per OP01B7 agreement, may now prepare a TDO and recommend organizations to perform the research.

The NAVSEA 55W5 proposed advanced development (6.3) human engineering research program is primarily directed at solving problems existing in the fleet today. Specific research efforts were suggested to address human engineering problem areas identified through fleet feedback, including results of crew surveys and ship riding exercises whereby human engineering specialists observe and measure personnel performance during actual at-sea operations. The human engineering problems thus identified were classified into five specific research issues:

- design of total ships
- design of alarms, noise levels and communications
- design of lighting, placards and labeling
- design and use of personnel protection systems
- women aboard ships.

Human Engineering Design of Total Ships This most important PD&NJ deals with a proposed phased approach to identify, analyze, store and use information from the fleet in order to solve ship problems by reflecting solutions in new ship design specifications. This process will identify the most recurrent and critical problems in the fleet and sponsor research to obtain solutions to these problems; solutions that could be implemented in emerging system designs, or, if sufficiently critical, in engineering change proposals (ECPs) for redesign of existing systems.

The effective integration of human engineering into total ship design will result in the application of several separate although interrelated products: 1) a system, including procedures, materials, and data for collecting, validating, prioritizing, and analyzing human engineering lessons learned data in existing systems and feeding these lessons back to ship system designers as fleet feedback to influence the design of emerging systems; 2) improved design and procurement specifications addressing the application of human engineering in the design of ship systems and supporting the assessment of the adequacy of the planned human engineering effort; and 3) tools and techniques for determining the optimum role of man vs. automation in the control of ship systems, and methods to forecast and describe personnel skill and system manning requirements and their implications for system designers in terms understandable to the designers.

The total ship research thrust addresses human engineering problems currently being encountered in the fleet. These problems include human performance and safety deficiencies in such areas as: ship arrangements, maintenance access and workspace, console and workstation design, environmental effects, workloads and workload distribution, and man-machine interface design. Human engineering problems in ship arrangements include: inefficient and ineffective layout of adjacent spaces to facilitate traffic patterns, arrangements that contribute to human error and delayed response, and facility layouts that impair personnel safety. Research questions in the arrangements area center on the methods and techniques to develop arrangements concepts that are effective, efficient and safe. Arrangement issues include compartmentalization, equipment accessibility, and compartment configuration to enhance information flow, team operations, traffic patterns, emergency egress and maintenance.

Shipboard maintenance access and workspace problems include the all too frequently encountered situation where a component simply cannot be accessed, or can only be accessed with extreme difficulty, such as where other components must be removed or disassembled to enable access, or where access to the component poses safety hazards to the maintenance personnel or to the other components. Research issues include the development of human engineering

interfaces with logistic access control, and the use of human engineering CAD/CAM programs to assess the accessibility of alternate design concepts.

Shipboard console and workstation design problems include a high incidence of operator errors and excessive time to perform operational sequences. As previously noted, the GAO reported in 1981 that over 50 per cent of all military system failures are due to human error. Further studies indicate that 20-40% human error reduction can be achieved by proper human engineering design.

Many of the systems being introduced to the fleet today do not exhibit a concern for human operator performance. Research issues include development of methods to reduce the incidence and effects of human error, the development of human engineering design standards and design criteria to guide the design of shipboard workstations, and development of guidelines to support the design of user-computer interfaces including interactive dialogues, information display organization and formatting, and alert prioritization schemes.

Environmental effects problems currently being encountered on board ships include: performance of topside activities in the cold, heat stress in engineering spaces, effects of weather, and ship motion effects. Research issues include developing human engineering design concepts and criteria for operation in extreme cold and hot environments, and determining the effects of weather and ship motion on human performance and safety.

The problems encountered with shipboard man-machine interfaces usually include locating controls and devices out of reach, locating displays where they cannot be seen, much less read, designing ladders which cannot be climbed by personnel carrying normal loads, designing passageways and hatches that cannot accommodate larger crew members wearing bulky clothing, installing equipment in a way that puts personnel in proximity to safety hazards, and generally failing to design ship equipment items in terms of the capabilities and limitations of the personnel who must operate, control, maintain or otherwise use them. Research issues include development of design standards and specifications and refinement of methods for evaluating alternate equipment layouts early in the design process.

Design of Alarms, Noise Levels and Communications. Critical problems exist in ships today in the inability of personnel to effectively hear and interpret annunciator alarms in some shipboard noise environments, the conduct of effective communications, and the interference of alarms and voice communications. Research thrusts in the alarm area include developing techniques and data to ensure human reception, understanding, discrimination and localization of alarm signals. Improved alarm reception and recognition techniques will include: altering the power spectra, frequency and characteristics of alarms to enhance perception and discriminability, and to unmask signals from noise; using visual cues to enhance auditory alarms; reducing false alarm rates; applying priority coding and localization coding; and relying on other sound elements for the alarms, such as speech and coded noise. Communication research issues include methods to ensure intelligibility and to reduce interference effects of noise and signals. Communication improvement techniques include standardized message format, visual displays to support auditory communications, and communication through coded sounds as well as voice. Time phasing and coding of alarm messages relative to system degradation and system failure are also included. The system operator must have adequate knowledge of the degradation of critical system parameters in order to take appropriate corrective action within human response time limitations.

Design of Lighting, Placards and Labeling. A human engineering problem on board ships is the determination of lighting requirements and the design of labels and placards to be readable in that lighting environment. The research issue is to develop methods and measures to assess effects of lighting levels and presentation of messages on the readability of labels and placards. A product of the research effort would include specifications for lighting and color coding of labels and placards consistent with task and discriminability requirements.

Design and Utilization of Personnel Protection Systems. Given the expected CBR environments of future conflicts, development of methods for personnel protection must be given the highest priority. Two classes of protection methods have been identified for shipboard application: collective protection systems (CPS) and individual protective ensembles (IPE). Requirements for protection at all ship stations must be established, and the impacts of each type of

protection on crew performance of assigned duties must be assessed. Techniques for activating, monitoring and maintaining CPS must be developed. Concepts and criteria for designing IPE to minimize adverse effects on operator performance capability must be developed.

Women Aboard Ships. The major consideration associated with the introduction of women into ships is that ship spaces and equipment have been designed for the male population. Required forces may exceed the capability of most women. Reach envelopes may extend beyond the capacity of women sailors. Consoles and control panels have been sized for the male operator and can be virtually inoperable by smaller sized women. The research issue is the development of design principles to facilitate the accommodation of women on ships. These principles will include summary anthropometric data for women, equipment design and techniques to offset the problems.

6) 6.3 Arctic-Cold Weather Research

As a separate but collateral effort, the human engineering branch has proposed to the arctic cold weather SCIB a human engineering research program for dealing with cold weather problems. Such problems run the gauntlet from deicing, to performing replenishment, to topside maintenance, to such simple tasks as standing or walking on a ship's deck in the cold environment. Here again, data from the fleet would be analyzed to determine problem prioritization. On review of proven solutions, and based on the results of limited special studies or literature reviews of prior research, a design or operational solution would be recommended.

7) 6.3 Ship Motion Effects Research

NAVSEA Code 55W54 has also been concerned with the specific effects of ship motion on human performance and safety. The code has a small R&D program underway with DTNSRDC to investigate motor skills and task performance at various ship locations and as a result of ship motions.

8) 6.4 NAVSEA 55W54 Human Engineering R&D Program

NAVSEA supports a number of ship human engineering design efforts through direct funding by Ship Acquisition Program Managers (SHAPMs). Among the ship designs currently funded are: destroyers, submarines, oilers, and transports. In addition, OPNAV 01B7G has discussed with NAVSEA the potential use of 6.4 funding for human engineering problems directly related to specific ship designs.

9) Summary

The underlying philosophy governing the management of human engineering research efforts in NAVSEA 55W54 is that these research activities be directed to solving existing or anticipated problems in the fleet. The approach to conducting the research begins with an effort to identify, validate and prioritize human engineering problems. This activity will involve acquiring fleet feedback data on problems from a variety of sources including: interviews of operational personnel; review of CASREPS, INSURV reports, COMOPTEVFOR reports, Naval Safety Center reports, etc.; and observation of ongoing shipboard activities at-sea. When problems have been identified, validated, and prioritized, alternate methods for correcting selected problems will be developed. These will include research literature/ data base review to determine if practical solutions already exist, and, if not, to plan and propose appropriate research efforts to OPNAV. Upon collecting information on available strategies and alternatives, solutions will be evaluated and tradeoffs of alternate solutions will be performed. As appropriate, these "best solutions" will be reflected in new ship design specifications or ECPs. In this way, SEA 55W54 plans to close the loop in getting to the fleet design solutions to their problems - solutions which incorporate the accumulated state-of-knowledge or specific conclusions of the research community.

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